Methane Purification for Oxygen Recovery

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ABSTRACT

For long-term space missions, maximized resource recovery is essential to sustain the supplies of astronauts. A system for recovering oxygen from carbon dioxide (CO_2) is the Sabatier Development Unit (SDU). Methane (CH_4) forms the secondary product of the system and contains unreacted CO_2 and water, which must be removed in order to maximize oxygen recovery. For this purpose, the Methane Purification Assembly (MePA) is designed with a bed of 13X zeolite, a commercial sorbent with an affinity for these two byproducts, and silica, which absorbs moisture from air. The MePA main bed is packed with over 1000 grams of 13X and 200 grams of silica. A cooling loop is connected to the MePA, allowing the system to be cooled during adsorption cycles. The sorbent bed can also be heated to desorb the zeolite, allowing the assembly to be reused. The cooling system and zeolite bed are connected with pre-fabricated duct work and the entire MePA is insulated. Completion of the fabrication, assembly, integration and testing of the MePA while integrated with state-of-the-art CO_2 reduction hardware marks a first for NASA technology development. Integrated testing results of the system provide crucial data for the development of future life support systems.

OBJECTIVES

- Pack the MePA bed with sorbent
- Assemble the cooling system and duct work around the bed
- Fully leak check and insulate the assembly
- Install the MePA into the Environmental Chamber (E-Chamber)
- Integrate the MePA with the SDU
- Draft a Test and Checkout Procedure

METHODOLOGY

The Sabatier reaction occurs within the SDU:

$$CO_2 + 4\,H_2 \rightarrow 2\,H_2O + CH_4$$

Once exiting the SDU, the CH_4 product stream enters the Plasma Pyrolysis Assembly (PPA) for further post-processing. There, leftover CO_2 reacts with carbon, and water reacts with methane, to form carbon monoxide (CO). The CO and water both foul the Acetylene Separation Assembly (ASepA) downstream. Once fouled, the ASepA cannot remove acetylene from the PPA effluent, limiting the purification of H_2. The MePA is placed upstream of the PPA to purify the stream through adsorption. Physical adsorption is the interaction between a molecule and a surface. In the case of zeolites, this interaction is based on size exclusion.

Figure 1: 13X Zeolite

A temperature control system is built around the bed in order for the system to be reused. Because this adsorption process is exothermic, zeolites perform more efficiently in cool conditions. Thus, the adsorption phase utilizes a facility chilled water cooling loop. For desorption, four heating rods within the bed warm the system to a maximum temperature of 300°C, evoking the sorbent to release captured molecules.

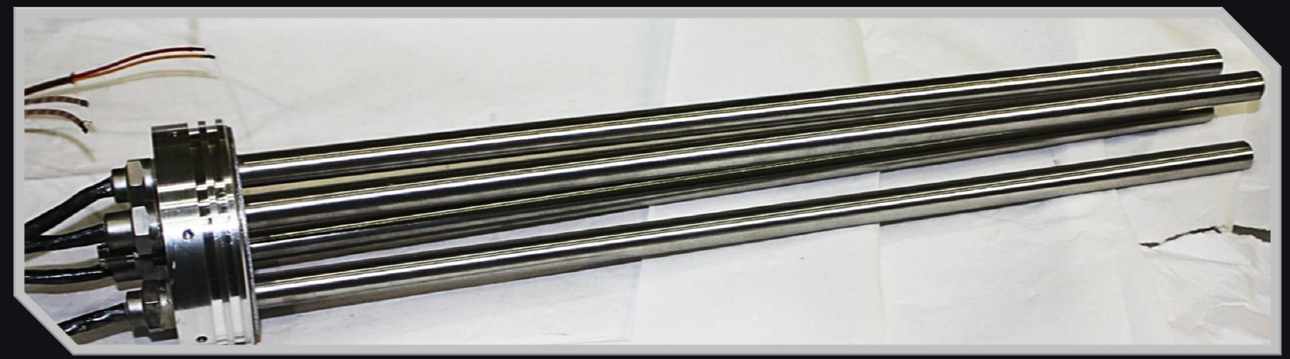

Figure 2: The four heater rods of the MePA bed, held in place by an endcap

ASSEMBLY

Sorbent Bed:

- Bed tube, endcaps, and perforated plates were fabricated at an off-site machine shop.
- Q-fins and duct work were ordered commercially.
- The main bed was designed with four heater coils and packed with Grace Davison 13X zeolite, silica, and glass beads. The end-caps contained O-rings and were screwed on airtight.
- Assembly was baked to remove any moisture adsorbed during the packing process.

Figure 3: Steel tube, plus endcaps, plus zeolite equals a packed, sealed MePA bed

- Six Q-fins were screwed on with a layer of heat transfer compound inside each.
- Entire bed was fit inside of a 7-inch duct. Remaining duct work and cooling system was assembled around the bed.

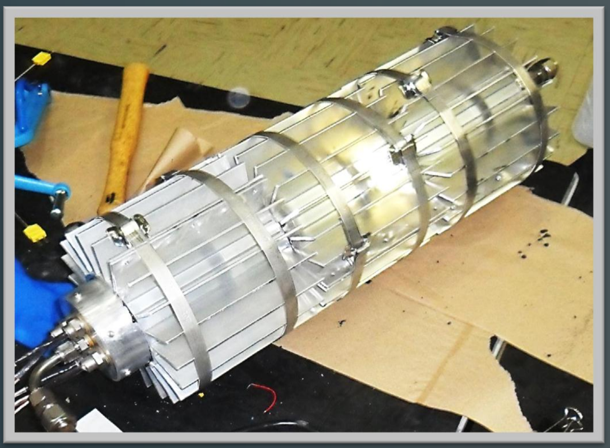

Figure 4: Packed bed with Q-fins attached

Cooling Loop:

- A cold plate with a cooling loop for facility chilled water had six holes drilled in it. Six modified heat sinks were each screwed into these holes with three washers and Silver Goop.
- Thermoelectric devices were placed between each sink and the plate, and were tied into a terminal.
- Thermistors were taped onto the opposite side, and glued to the heat sinks on both ends.
- A layer of room temperature vulcanizing silicone covered the wires to make a flat surface. A piece of blue aerogel insulation was fit to cover the wires.
- The cold plate was screwed into a cooling bar, which contained a layer of insulation and Kapton tape.
- A fan was placed at the end of this cooling bar to blow cool air directly over the sinks.

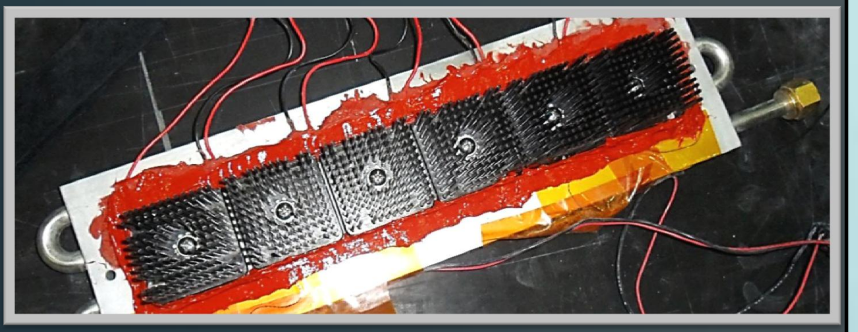

Figure 5: Cold plate with six heat sinks, thermistors, and thermoelectric devices. A layer of RTV covers the wires to create an even plane.

Figure 6: Cooling bar insulated on the inside

Full Assembly:

- Each joint was wrapped with Kapton tape and/or aluminum tape to minimize leaks.
- The MePA was insulated with 3-4 layers of aerogel, silica, and rubber. Each piece was tied on with steel wire or insulation tape.

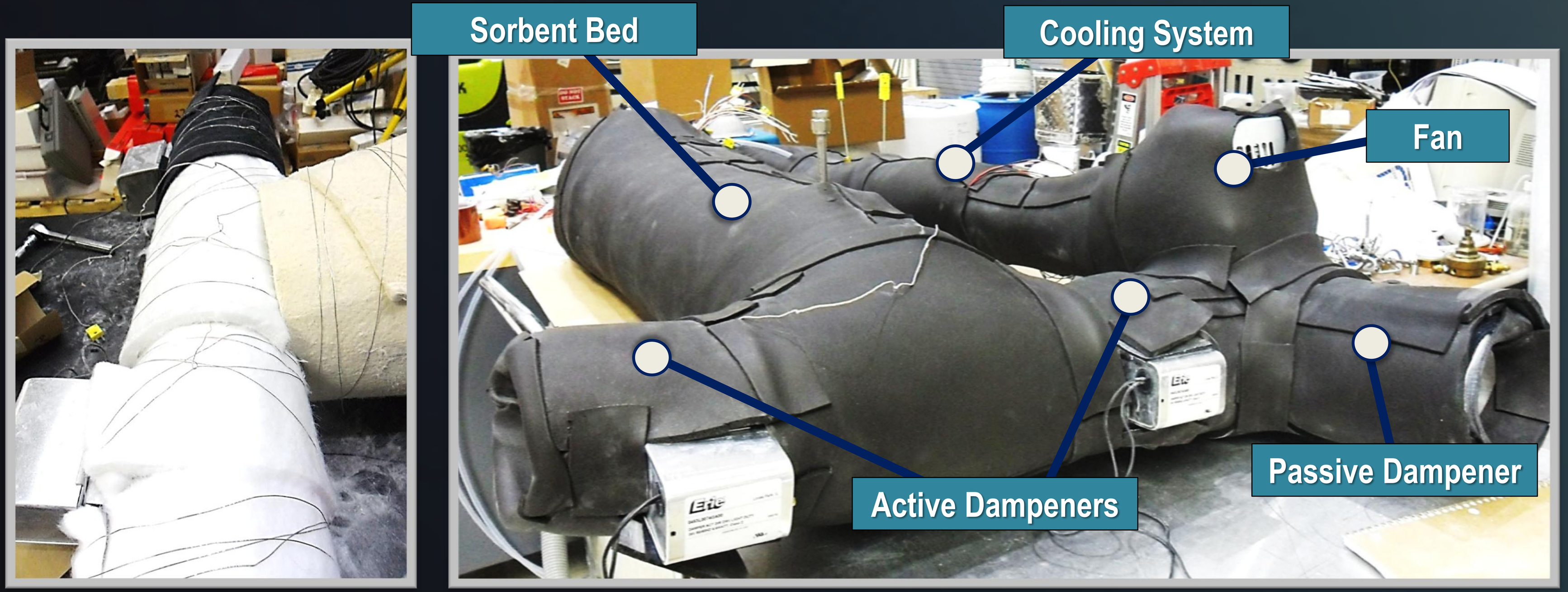

Figure 7: Left - Interior layers of aerogel insulation; Right - Full MePA assembly with exterior rubber insulation

INTEGRATION

MePA was integrated with the SDU in the E-Chamber. Because of the space constraint and future addition of the ASepA and PPA, it was placed vertically. For this reason, a mounting plate was crafted to support the assembly from all angles.

Figure 8: E-Chamber from the outside

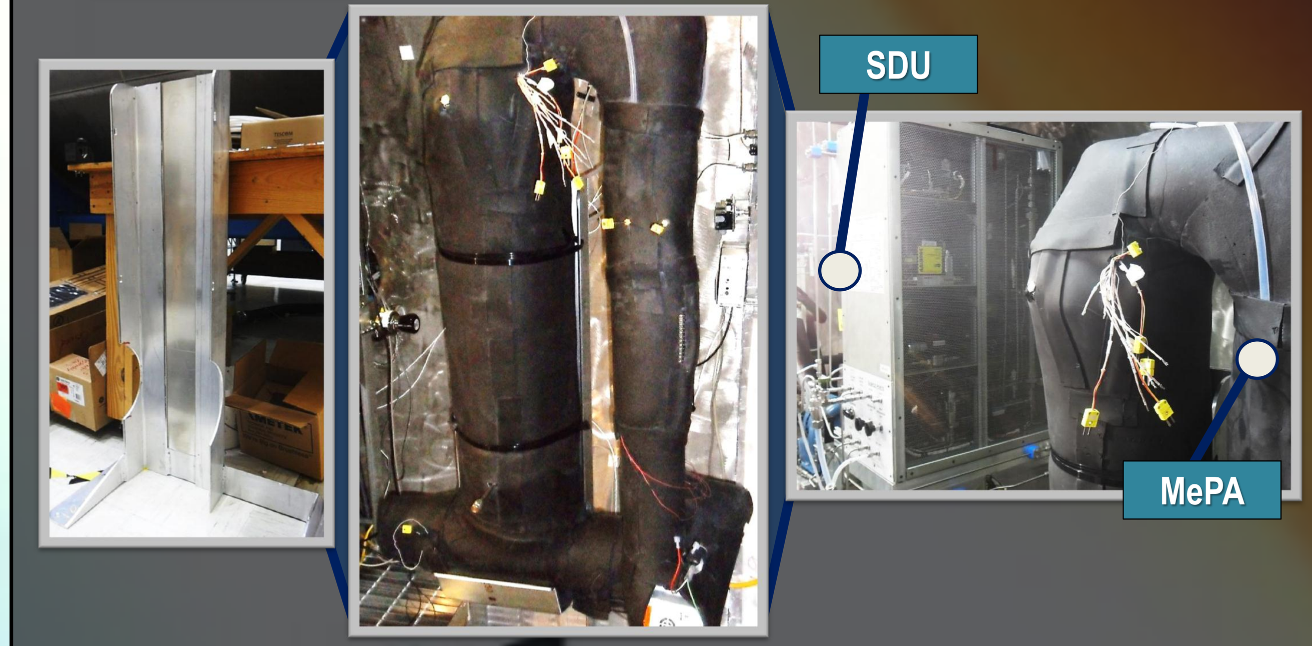

Figure 9: Left – Free standing mounting plate; Middle – MePA bound to the mounting plate; Right – MePA installed in the E-Chamber beside the SDU

The mounting plate was welded from stainless steel. MePA was held onto it by zip ties and a steel cradle. The mounting plate and MePA were bolted down to the grated E-Chamber floor with large washers. A bracket from above was fabricated to steady the assembly. Finally, MePA was plumbed into the SDU with all of its test stand components.

PLANNED TESTING

Initial testing of the MePA bed will involve two phases. The objectives of these phases are:

- **Phase I:** To observe the loading of water and CO_2 and the breakthrough profile for CO_2 from SDU methane effluent in the MePA
- **Phase II:** To optimize the MePA regeneration procedure to ensure complete regeneration in a single half-cycle

Both phases will perform trials where the SDU feed H_2:CO_2 ratio is 3.5:1, and alternatively 4.5:1. The Test and Checkout Procedure has been drafted, and a Test Readiness Review will occur in the near future. Data gained from these tests will include how long it takes to cool the bed after desorption, and how much desorption is possible.

FUTURE WORK

- May design an assembly with 5A zeolite, which also has an affinity for CO_2 and water. 5A zeolite performed well in theoretical models.
- MePA will eventually be integrated into the PPA and the ASepA for a more complete recovery system.

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